BORE HOLE STUDIES OF THE NATURALLY IMPOUNDED FILL AT SANTA BARBARA, CALIFORNIA

TECHNICAL MEMORANDUM NO. 49

BEACH EROSION BOARD

CORPS OF ENGINEERS

AUGUST 1954

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

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FOREWORD

Beach studies usually involve a study of the lateral variation of beach sediment properties, but seldom if ever have analysed the variance of these properties with depth or, in particular, the lateral variance of these properties at some datum underlying the surface layer. A study of this latter type could be particularly informative as it would give much information as to how sand accumulates in an area, and whether the surface properties remain essentially the same at a particular depth as the shore moves seaward in an accumulating area. A series of core samples were collected from the area of accumulation behind the Santa Barbara, California breakwater, and these cores analyzed; the analysis is presented in the following report. Insofar as is known, this is the first attempt to drill holes through a natural accumulation of sand above a shallow water offshore area in order to study sedimentary processes.

This report was prepared at the University of California in Berkeley in pursuance of contract DA-49-055-eng-8 with the Beach Erosion Board which provides in part for the study of sedimentary processes as a method of determining the source of beach materials. The authors of this report, Parker D. Trask, and Theodore Scott, are Research Engineers at that institution.

Views and conclusions stated in this report are not necessarily those of the Beach Erosion Board.

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BORE HOLE STUDIES OF THE NATURALLY IMPOUNDED FILL

AT SANTA BARBARA, CALIFORNIA

by
Parker D. Trask and Theodore Scott
Research Engineers, University of California

Introduction

A breakwater was built at Santa Barbara about 25 years ago to provide protection for sea-going vessels and pleasure-yachts. This breakwater was dog-legged in outline, one leg extended seaward for a distance of 1400 feet from the former shore line, the other leg a like distance parallel to the shore. Within a few years the alongshore drift of sand from west to east had filled the area west of the breakwater and sand had begun to move along the side of the breakwater and accumulate within the harbor, forming a sand island as shown in Fig. 1. As 800 to 1000 cubic yards of sand a day normally flow along the beach in this area, in a few years so much sand had accumulated within the harbor that it became necessary to remove the sand by dredging. Since that time the sand fill within the harbor has been removed by dredging every two or three years. The sand is placed east of the pier, shown on Fig. 1, to replenish the beaches to the east which were cut off from their normal supply of sand by the breakwater. The periodic removal of the sand and the inconvenience of the sand fill in the harbor present a serious economic problem to the neighboring community. The Beach Erosion Board, as a consequence, has been studying the mechanics of the accumulation of sand adjacent to the breakwater for a number of years in order to find the most economical means of coping with the problem.

The Waves Research Laboratory of the Department of Engineering of the University of California at Berkeley, in recent years has been cooperating with the Beach Erosion Board in this work. In connection with these studies it seemed desirable to drill a series of holes through the fill that had accumulated west of the breakwater. As this fill overlay areas that formerly were covered by sea water, drill holes would penetrate not only sand that had accumulated above water as the area was filled up, but also would penetrate sands resting upon the sea bottom before the breakwater was built. Thus information as to how sand accumulates, both offshore and on the beach would be obtained. The present paper presents results of this drilling program.

A series of seven bore-holes were drilled in the filled area. The location of these bore-holes with respect to man-made improvements and bottom contours is shown in Figs. 1 and 2. An additional bore-hole would have been desirable near the knee of the dog-legged breakwater where the water originally was more than twenty feet deep, but buildings interfered with moving the drilling rig across the sand to that position.

Method of Drilling

The holes were drilled by a portable rotary drilling rig. No casing was used except for a two-foot pipe at the surface of the sand to guide the bit. The sand was sealed off with suitable quantities of drilling mud. The samples were taken with a split barrel sampler provided by Dames and Moore of San Francisco.

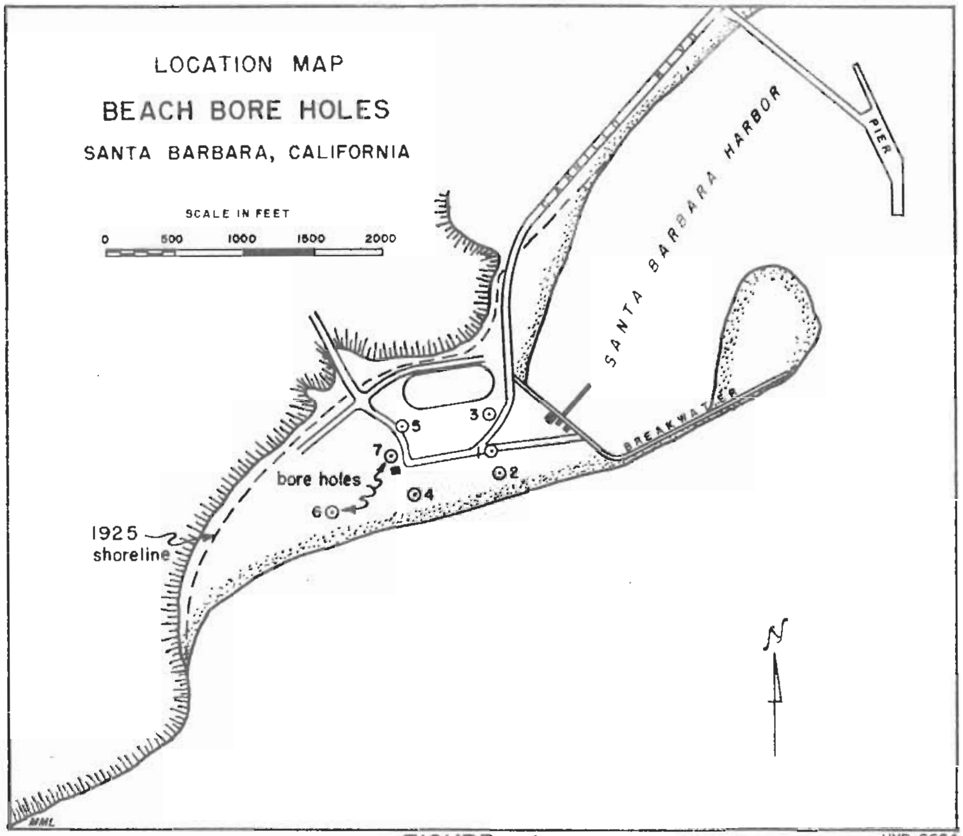


FIGURE 1

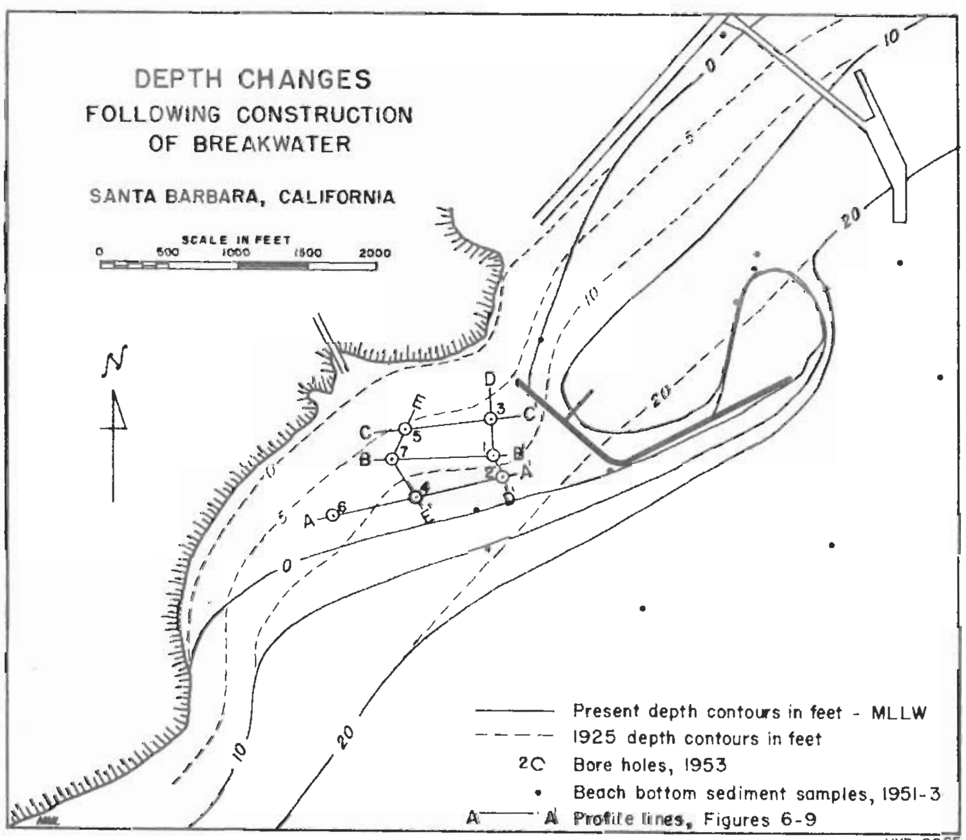


FIGURE 2

The bit of the sampler screwed on to the two halves of the split pipe. A steel tube placed within these two sleeves held the brass tubes in which the samples were collected. The brass tubes had a diameter of 2 inches and a length of 10 inches. The sampler was driven into the ground by means of a pair of jars weighing 700 pounds and having a stroke of two feet. Normally 25 to 50 blows were required to drive the sampler the normal sampling distance of 13 inches into the ground. This distance of penetration normally provided 3 inches of material in the bit and 10 inches in the brass tube. The sand in some parts of the fill was packed so densely that the sampling instrument did not penetrate the full 13 inches with 50 blows. The respective penetration for the individual samples is shown in Figs. 3-5, which present photographs of the individual cores taken immediately after they had been opened for laboratory study.

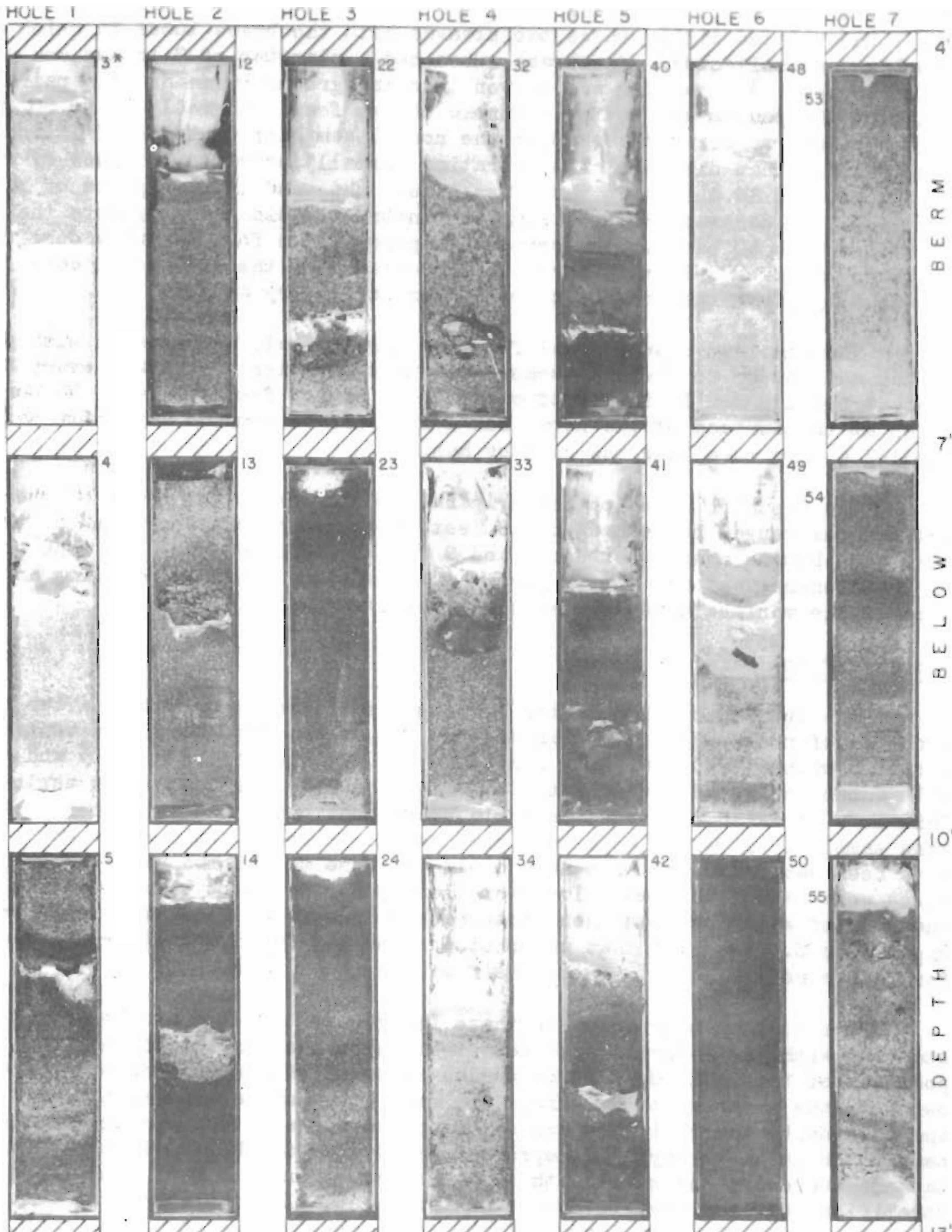
The samples, upon removal from the core barrel, were sealed with paraffine at top and bottom to prevent escape of water. Samples were taken every three feet, providing for 10 inches of core out of each 3 feet drilled. No cores were taken at the surface of the berm, but a few surface samples were obtained by pushing a core tube into the sand by hand.

The depth of water on the original sea bottom at the sites of these 7 drill holes ranged between 6 and 12 feet, and the thickness of sand on the original sea bottom ranged between 0 and 9 feet. The underlying bed rock consists of Pleistocene sand and clay. Pertinent data as to depth of drilling and thickness of the various types of sediment are given in Table II-A.

Process of Analysis

The opening of the samples for study presented a problem. After trying a number of procedures, the plan adopted was to saw the tubes in a vertical position with a band saw. The sand wore the teeth of the saw badly and a sizeable amount of water leaked out of the cores during the process of sawing. This loss of water prevented reliable determination of the wet density of the sand samples. It would have been prefereable to use plastic cores which would have been easier to saw, but none could be found to fit the sampler. After the tubes were sawed, the two halves were gently forced apart with a spatula and one half of each tube was then photographed in a moist condition, as shown in Figs. 3 to 5. The half that was photographed was dried and placed in storage for future reference. The other half was used for study.

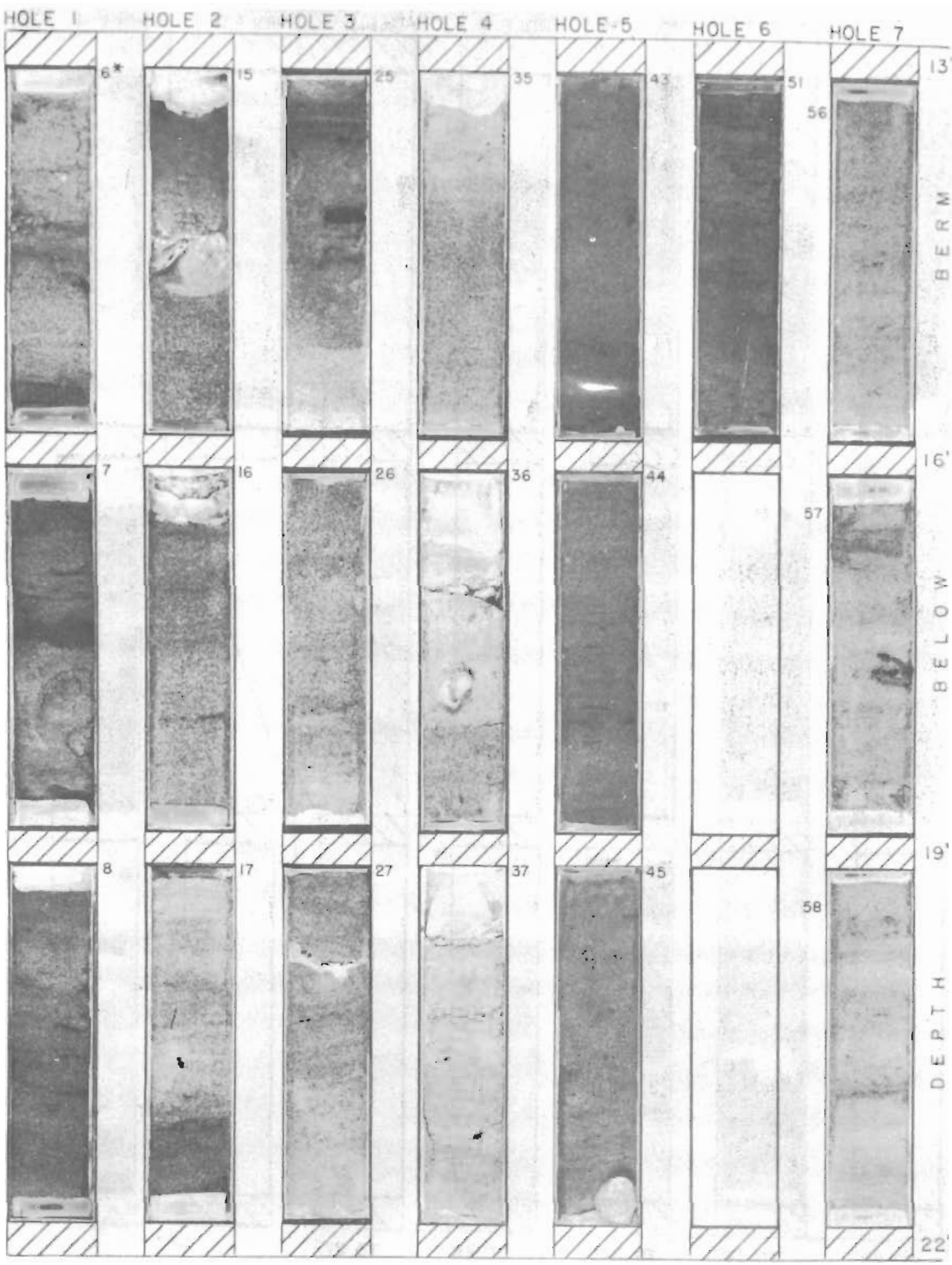
The cores are arranged in these figures by 3-foot depth intervals, starting with the interval of 4 to 7 feet below the surface of the berm. The position of the individual cores varies somewhat within each 3-foot interval, owing to the vagaries of drilling; but each core sample was taken within a specific depth interval,as shown on the photographs. Thus, though each core photograph shown on any line represents a similar depth beneath the berm, it may not represent the same depth in all cores. Hence, direct comparisons of stratification from core to core cannot be made. In some cores the sample did not rise to the full length of the core tube. Where possible, samples of sand from the bit beneath the core barrel were placed in the top of such core tubes, so that as much material as possible could be preserved from each depth interval. The presence of paraffine, which photographs white, in the upper part of the core tube indicates that the overlying sediment is from the bit. On Fig. 5 a few manually taken core samples from the upper 4 feet of the



* Sample numbers. Core samples are 10" long; see Table I for exact position in 3' sections.

PHOTOGRAPHS OF CORE SAMPLES
SANTA BARBARA, CALIFORNIA
Depth: 4 to 13 feet

FIGURE 3



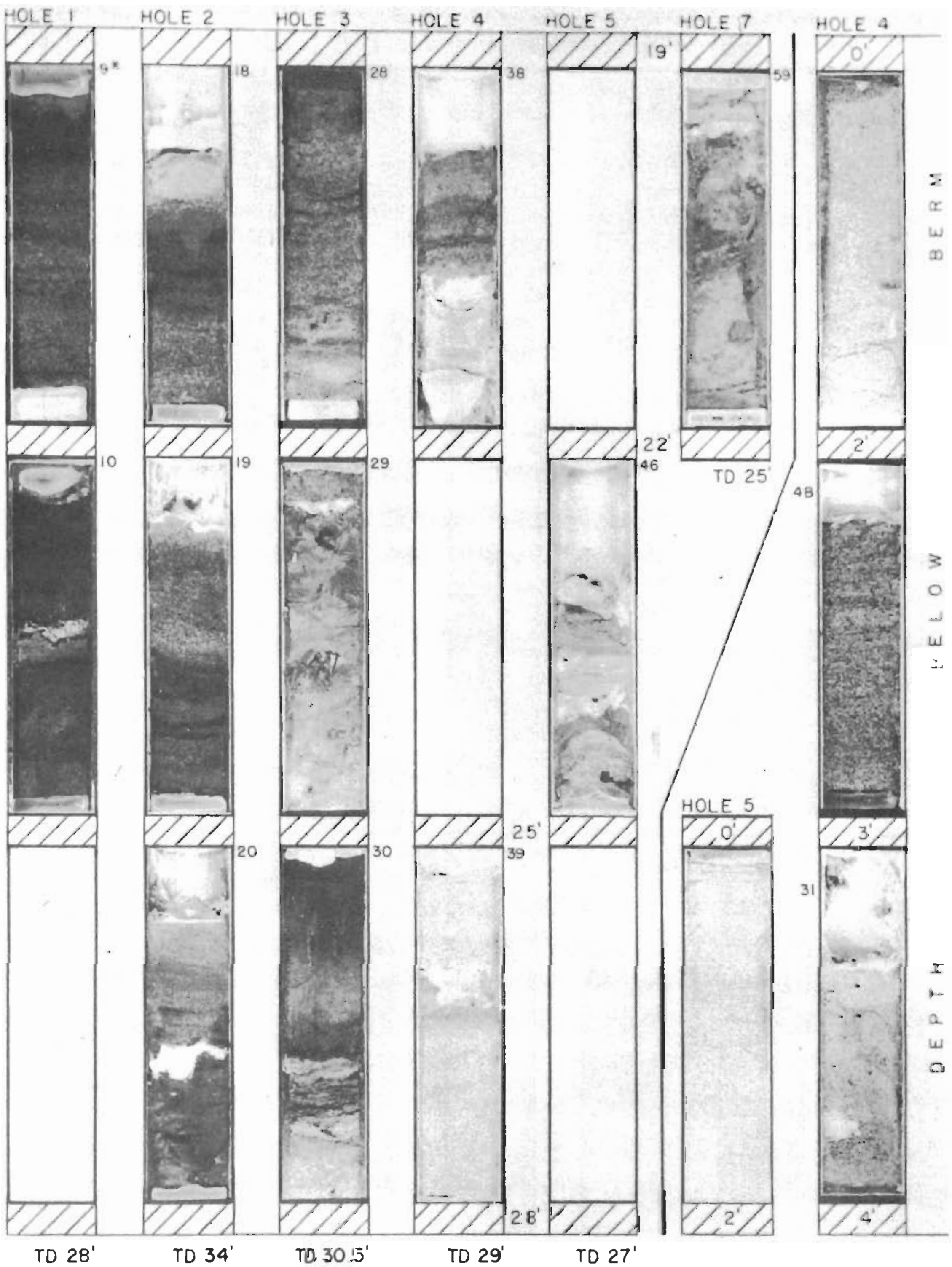
* Sample numbers. Core samples are 10" long.

TD 19'

PHOTOGRAPHS OF CORE SAMPLES
SANTA BARBARA, CALIFORNIA

Depth: 13 to 22 feet

FIGURE 4



* Sample numbers

Core samples are 10" long; see Table I for exact position in 3' sections.

PHOTOGRAPHS OF CORE SAMPLES
SANTA BARBARA, CALIFORNIA
Depth: 19 to 28 feet; miscellaneous

FIGURE 5

berm are shown. The two samples shown in this figure taken at depths of 2 and 3 feet were procured from a pit dug in the sand.

The upper core samples, that is, those near the surface of the berm, are light in color and are homogeneous, through semblances of stratification are seen in some samples, as for example, in Holes 6 and 7. Hole 5 at the westernmost end of the filled area shows dark material. The deeper cores are stratified to varying extent. Dark zones presumably representing concentrations of organic matter were encountered in several places. Cores taken at depths of 16 to 22 feet, near the level of the former sea bottom, contained fragments of seaweed and smelled of hydrogen sulfide when taken. The texture of the samples as seen from the photographs is remarkably uniform; this feature is well corroborated by the mechanical analyses and by data presented in Tables IV to VI.

The first procedure of analysis was to examine each core beneath the microscope for variations in grain size, color and the presence of organic debris such as kelp. A diagram was made of the stratification and structure of each core. From 3 to 6 samples an inch in length were taken from each core, or core and bit sample. The largest number of samples were selected from cores showing the greatest variation. Special effort was made to pick samples for analysis from the coarsest and finest parts of each core, so that the extreme variation in each core could be determined. The samples were analyzed by the conventional rotap procedure, using geometric-sized sieves.

The results of the analysis are presented in Table I and in Figs. 6 to 9. In Table I the three standard parameters are shown, namely, the median diameter (D_{50}) in microns, the coefficient of sorting, and the logarithm of skewness. These same parameters are shown graphically in Figs. 6 to 9. In these figures the bore holes are arranged along sections as given in Fig. 2. The median and coefficient of sorting are shown as ordinates on the right and left sides respectively of the columns representing the cores. The skewness is presented by a series of dots in the center of the column. The number of dots on either side of the center lines indicates relative size of positive or negative logarithm of skewness, as described in the legend of Fig. 6. The bottom of the sea floor prior to the construction of the breakwater is indicated on these figures by the line "1925 B". The sediments deposited prior to the construction of the breakwater lie between the line "1925 B" and the line labeled "Qsb". The depth contours of the original sediments, as shown on Fig. 2, are taken from U.S. Coast and Geodetic Chart 5261, published in 1927, and presumably represent the approximate position of the sea floor in 1925. For the purpose of analysis of the results, the depth prior to the construction of the breakwater has arbitrarily been assumed to be as indicated on these charts, but obviously the designated depths are only approximate.

Results

The results of the mechanical analyses have been summarized in Tables II to VII and on Figs. 10 to 14. Tables II and III present data on median diameter and sorting with respect to the three different types of sediments encountered, namely: (1) sand deposited in the area of fill after the construction of the breakwater, designated in Figs. 2 and 3 in terms of depth below ground surface; (2) sand accumulated upon the offshore area prior to the construction of the breakwater, designated on these figures in terms of depth

SANTA BARBARA BEACH PROFILE A-A′

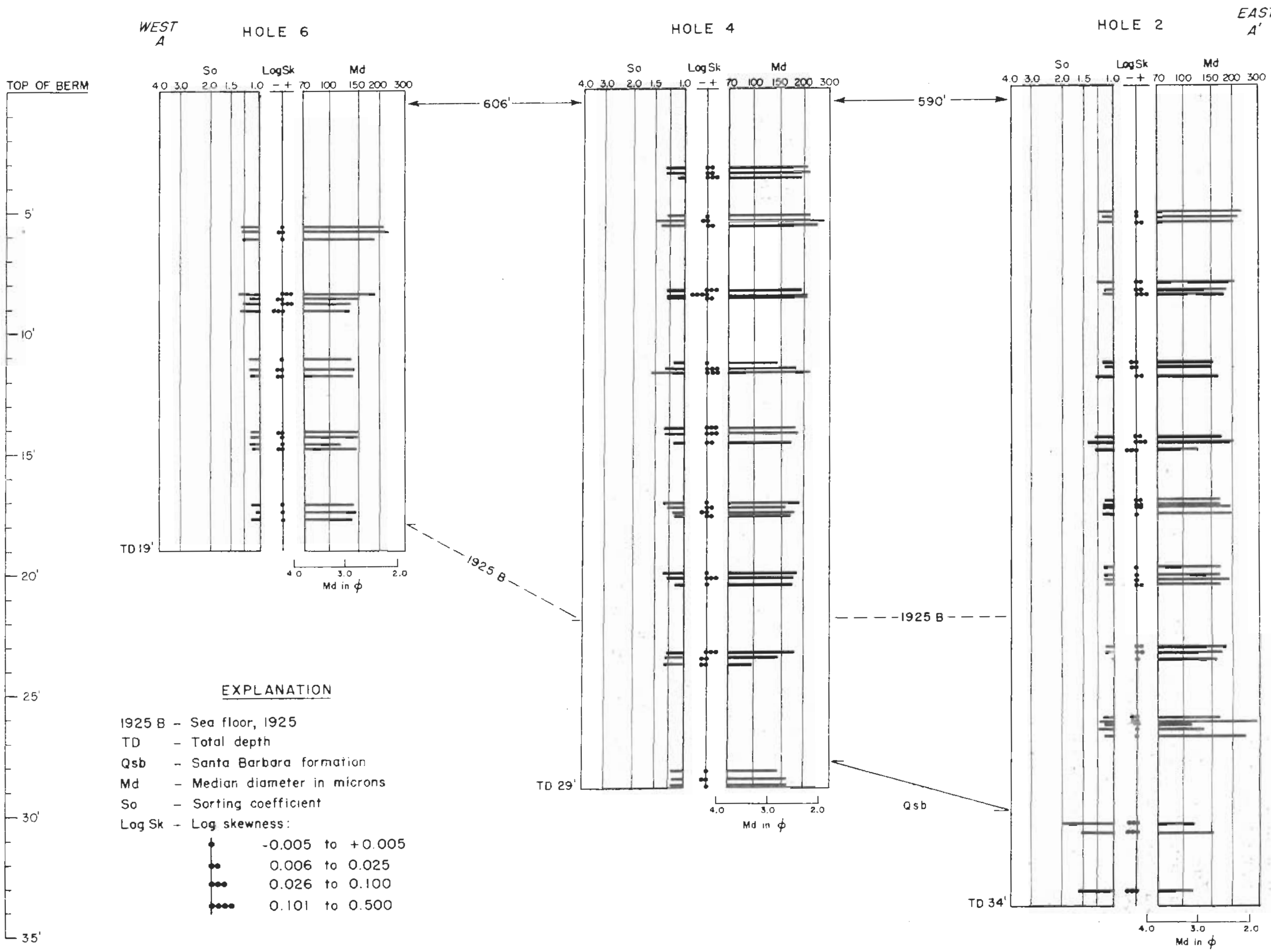


FIGURE 6

HYD-6673

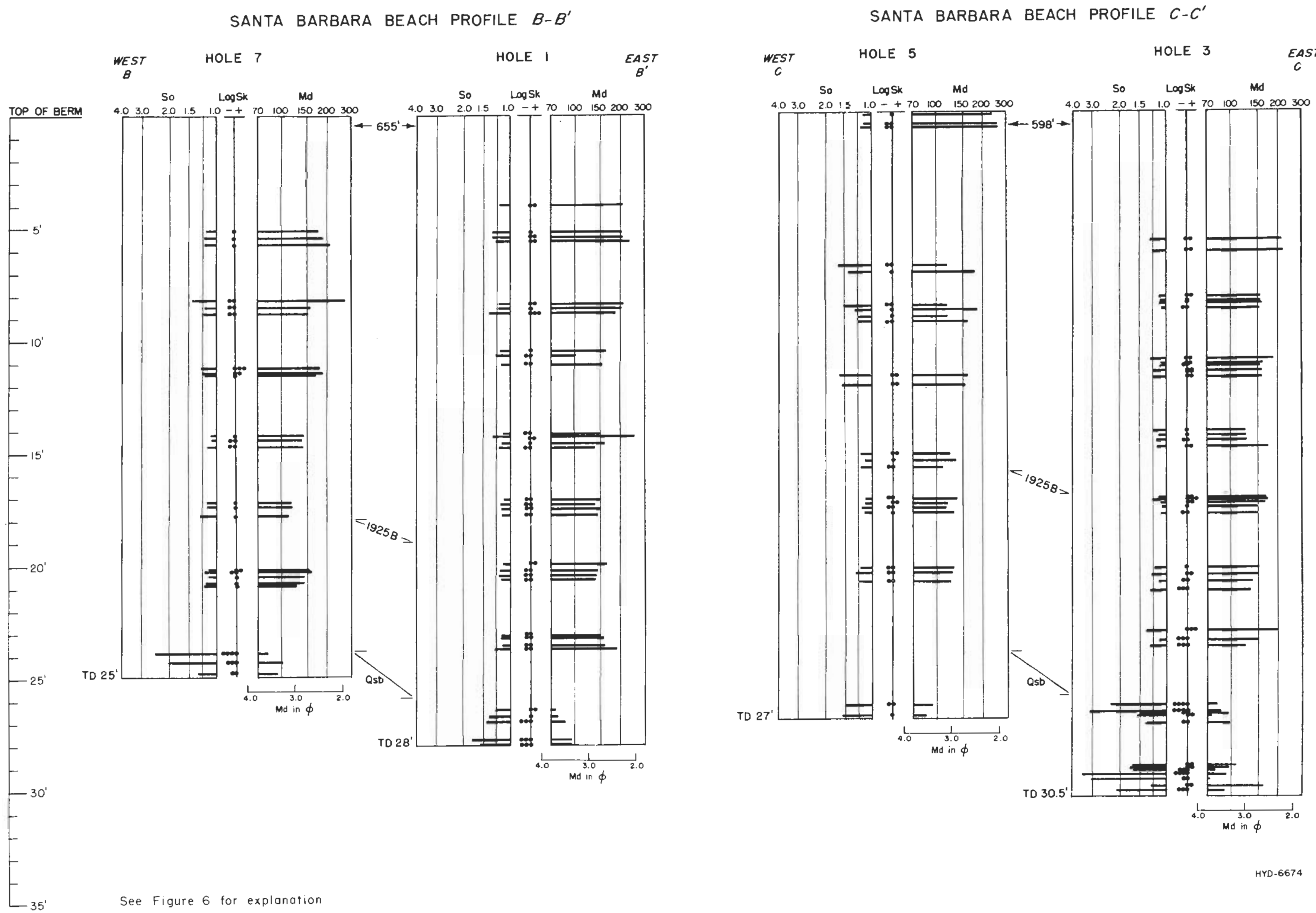
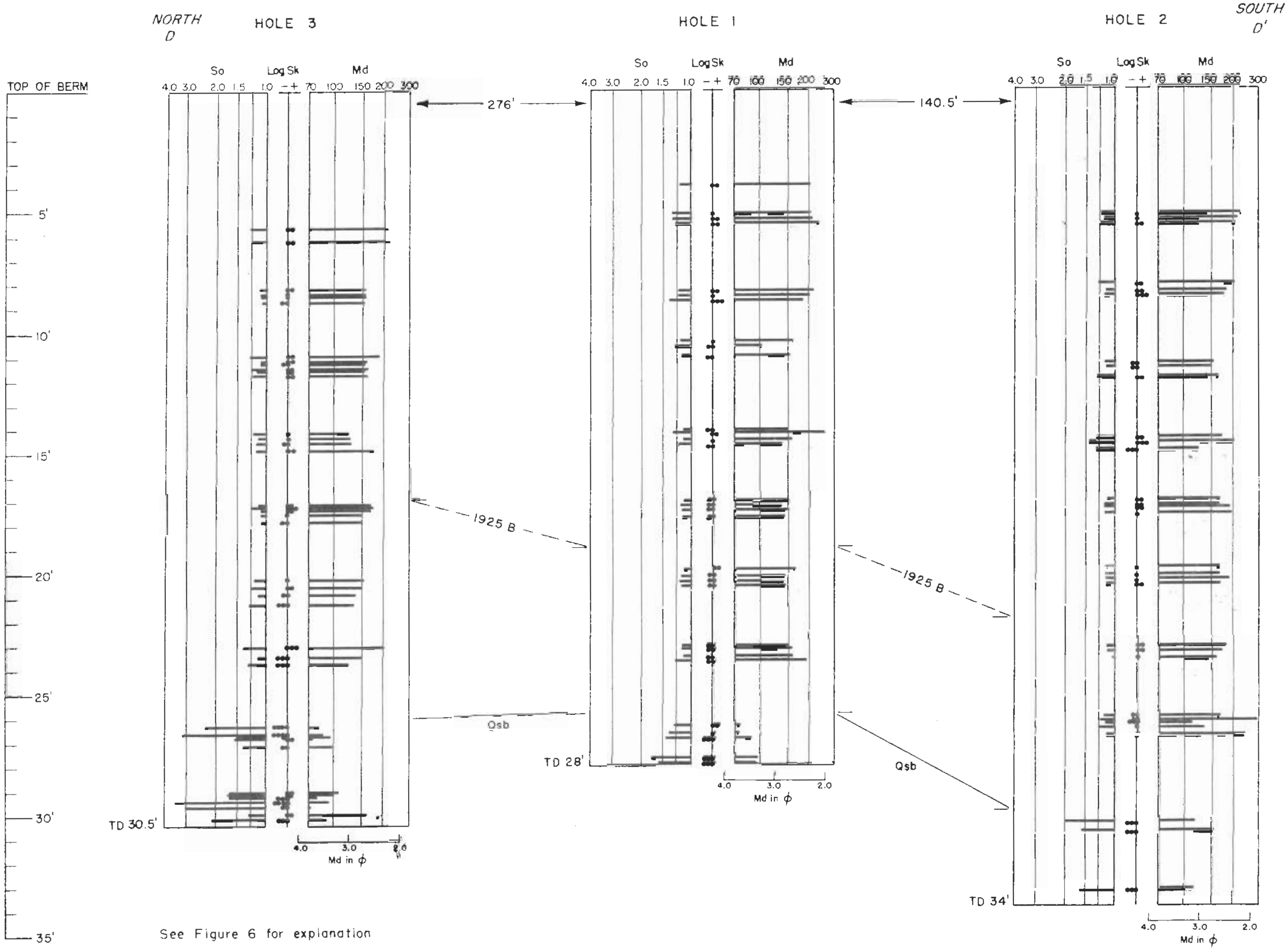

SANTA BARBARA BEACH PROFILE B-B'
WEST B
HOLE 7
HOLE 1
EAST B'
So
Log Sk
Md
4.0 3.0 2.0 1.5 1.0 − + 70 100 150 200 300
TOP OF BERM
5'
10'
15'
20'
25'
30'
35'
655'
1925B
Qsb
TD 25'
TD 28'
4.0 3.0 2.0
Md in φ
SANTA BARBARA BEACH PROFILE C-C'
WEST C
HOLE 5
HOLE 3
EAST C
598'
TD 27'
TD 30.5'
HYD-6674
See Figure 6 for explanation

FIGURE 7

SANTA BARBARA BEACH PROFILE D-D'



See Figure 6 for explanation

FIGURE 8

HYD-6675

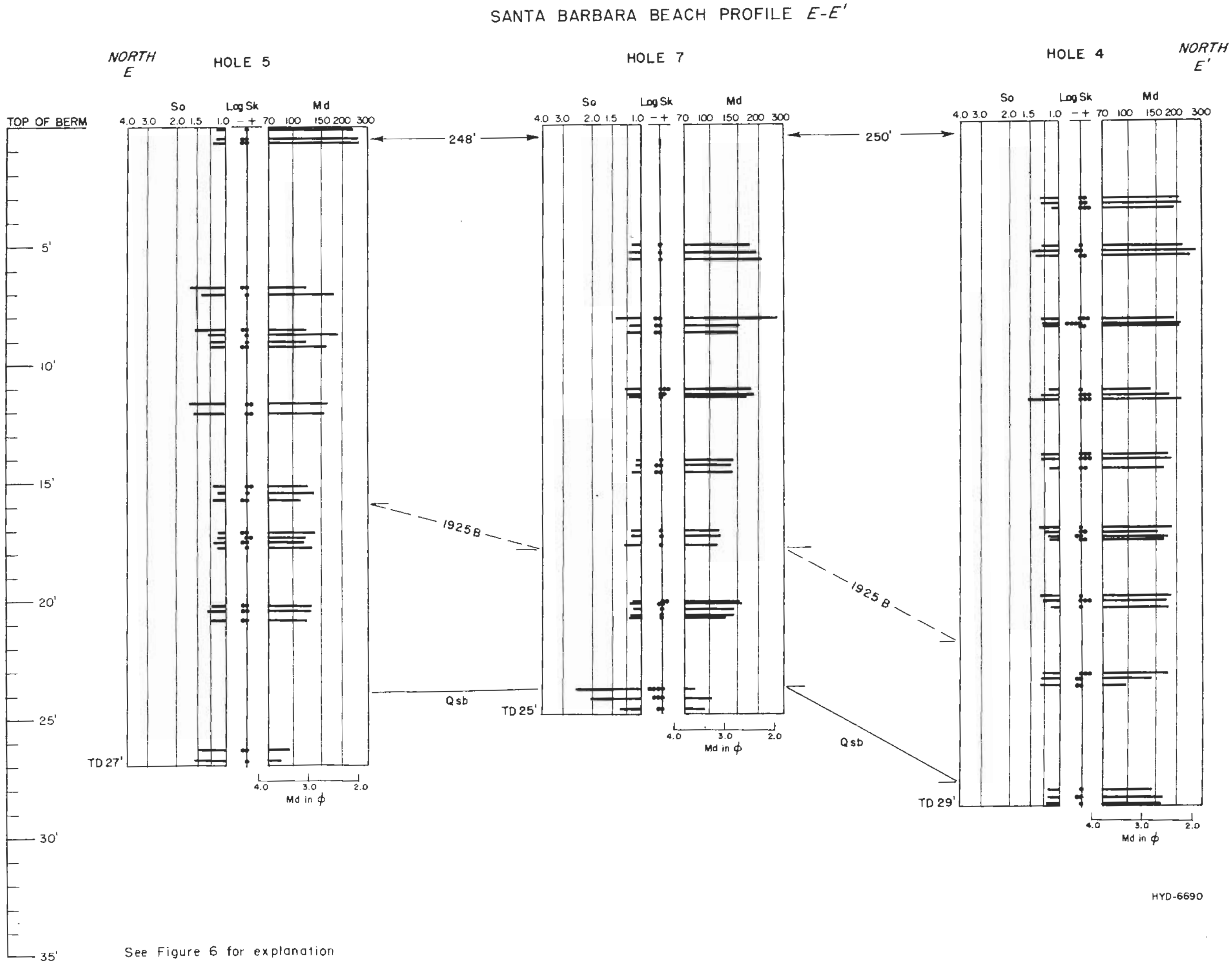

SANTA BARBARA BEACH PROFILE E-E'
NORTH E
HOLE 5
HOLE 7
HOLE 4
NORTH E'
So
Log Sk
Md
TOP OF BERM
4.0 3.0 2.0 1.5 1.0 − + 70 100 150 200 300
248'
250'
5'
10'
15'
20'
25'
30'
35'
1925 B
Qsb
TD 27'
TD 25'
TD 29'
4.0 3.0 2.0
Md in φ
HYD-6690
See Figure 6 for explanation

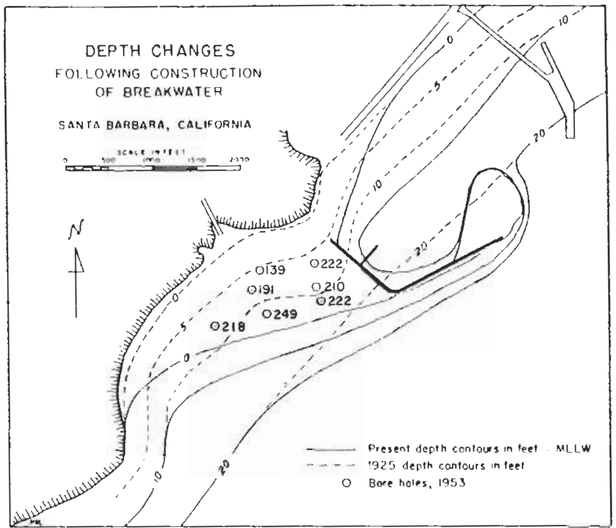
FIGURE 9

below 1925 sea botton, or as "1925 sediments"; and (3) Pleistocene sediments. The Pleistocene in this area consists of a series of thin-bedded sands, sandy clays and clays tilted to an angle of 25 degrees or more. Clay samples were not analyzed, as the present problem relates primarily to sand. The Pleistocene sands are more variable in size, sorting and skewness than the overlying beach and shallow water marine deposits, and perhaps in part are continental in origin. The Pleistocene is designated on Figs. 6 to 9 by the symbol "Qsb".

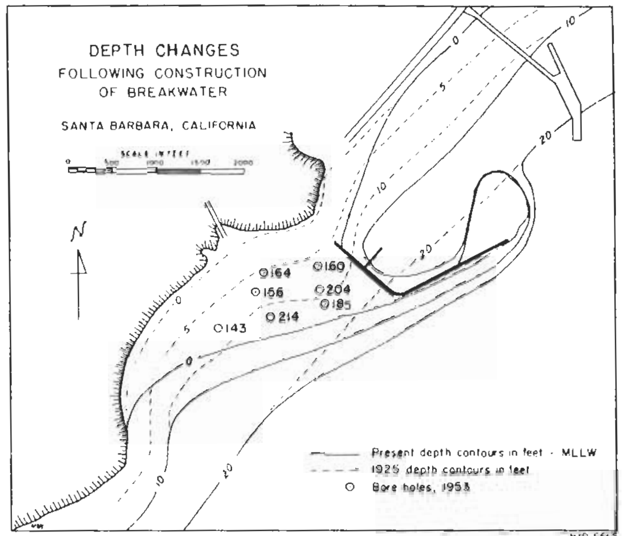
As shown in Table II, the grain diameter of the sand in the fill decreases more or less progressively from the top of the berm to the base of the fill. The average median diameter of all fill sediments in the 7 holes, as shown in the last column of the table, decreases from more than 200 microns at the surface of the sand fill to 150 microns at the base. The average of 177 microns for the depth interval of 19 to 22 feet beneath the top of the berm is based on holes 2 and 4 in which the samples are notably coarser than in samples from the other cores located nearer to the original shore. The sediments on the old sea floor, as indicated in Table II, are essentially constant with respect to depth. The average median diameter for each of these three depth intervals is approximately 150 microns. The Pleistocene deposits in general are finer than the recent sands. The average grain size is 95 microns.

The coefficient of sorting, as indicated in Table III, in general decreases progressively from the upper part of the berm to the base of the filled deposits, ranging from 1.27 near the top of the fill to 1.17 at the botton. The three tube samples taken manually in the beach sand at holes 4 and 5 have a lower coefficient of sorting than those at a depth of 4 feet. It would be desirable to collect additional samples in the upper 4 feet to determine whether this reversal is real or anomalous. The coefficient of sorting of the sediments below the 1925 sea bottom seemingly increases with depth, as the respective averages for depths of 3, 6 and 9 feet are 1.16, 1.23 and 1.30. That is, the sediments at shallow depth of burial are better sorted than the underlying sediments. However, as the number of samples is small, this trend may be anomalous. The Pleistocene deposits are more poorly sorted than the overlying marine deposits, the average coefficient of sorting being 1.58.

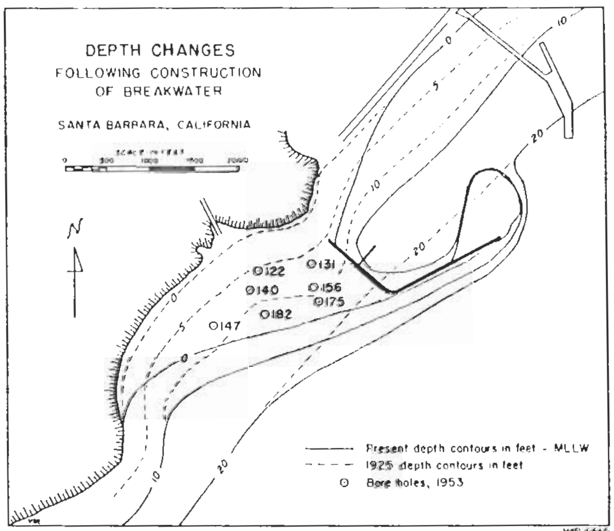
The data for the different depth zones given in Tables II and III vary among the different cores. This variation is related to the old shore line, as is shown in Figs. 10 to 12. The median diameter in each depth interval increases progressively seaward. The maximum grain size is in Holes 2 and 4 which are in the most exposed conditions where wave energy should be the greatest. Fig. 10 shows the variation in median diameter for samples of the fill deposits that accumulated after the breakwater was built. In the depth zone of 4 to 7 feet beneath the surface of the berm, the median is 249 microns in Hole 4 located near the present edge of the berm and 139 microns in Hole 5 near the old shore line. In the interval of 7 to 10 feet, the maximum is 214 microns in Hole 4, but the minimum is 143 microns in Hole 6, the westernmost hole. The grain size, however, is relatively small, 156 to 164 microns in Holes 1, 5 and 7, which are near shore. The depth zone 10 to 13 feet shows no distinctive areal difference, and is not plotted. The depth zones 13 to 16 feet and 16 to 19 feet show the same general seaward increase in grain size as do the upper 2 zones. The grain size in these depth zones for respective holes, however, is smaller than in the upper depth zones. This relationship accords with the data shown in Table II, which indicate that on the average the grain size decreases downward in the cores. A less distinctive seaward increase in grain size is indicated for the old sediments deposited on the sea floor



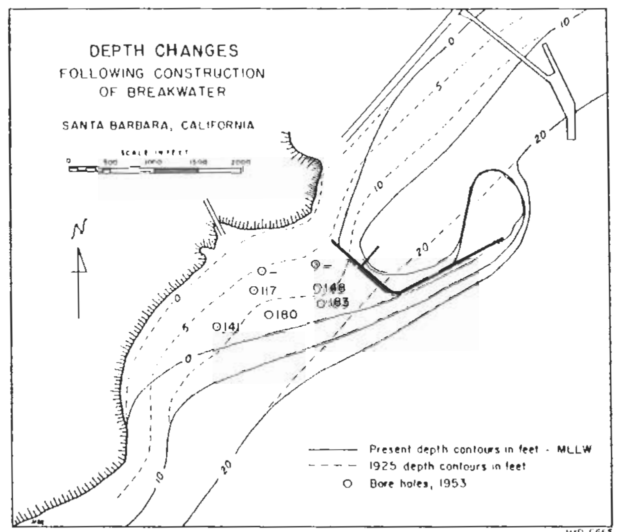
a. 4 to 7 feet below surface of berm



b. 7 to 10 feet below surface of berm



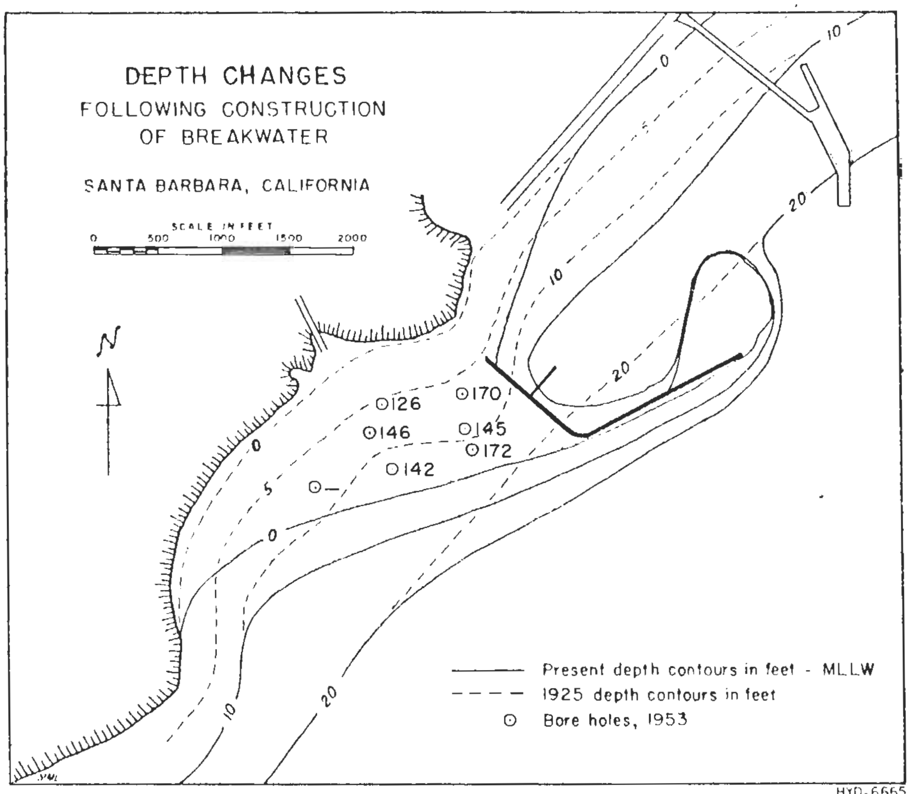
c. 13 to 16 feet below surface of berm



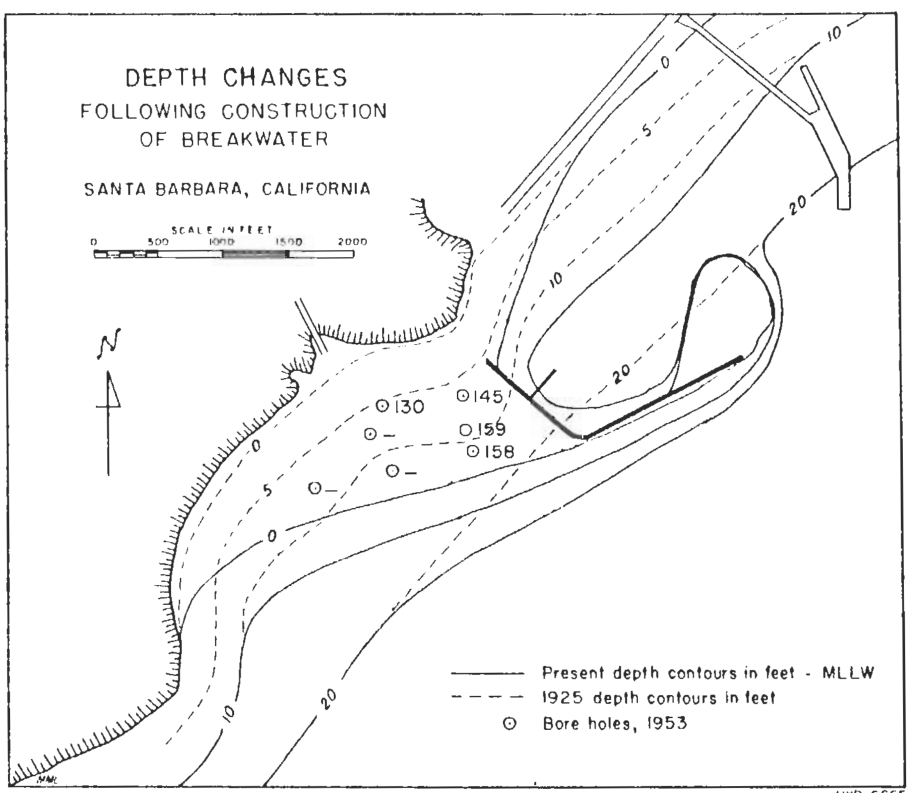
d. 16 to 19 feet below surface of berm

MEDIAN DIAMETER OF CORE SAMPLES IN MICRONS

FIGURE 10



a. 0 to 3 feet below surface of 1925 sediments



b. 3 to 6 feet below surface of 1925 sediments

MEDIAN DIAMETER OF CORE SAMPLES IN MICRONS

FIGURE 11

prior to the construction of the breakwater, as shown in Fig. 11.

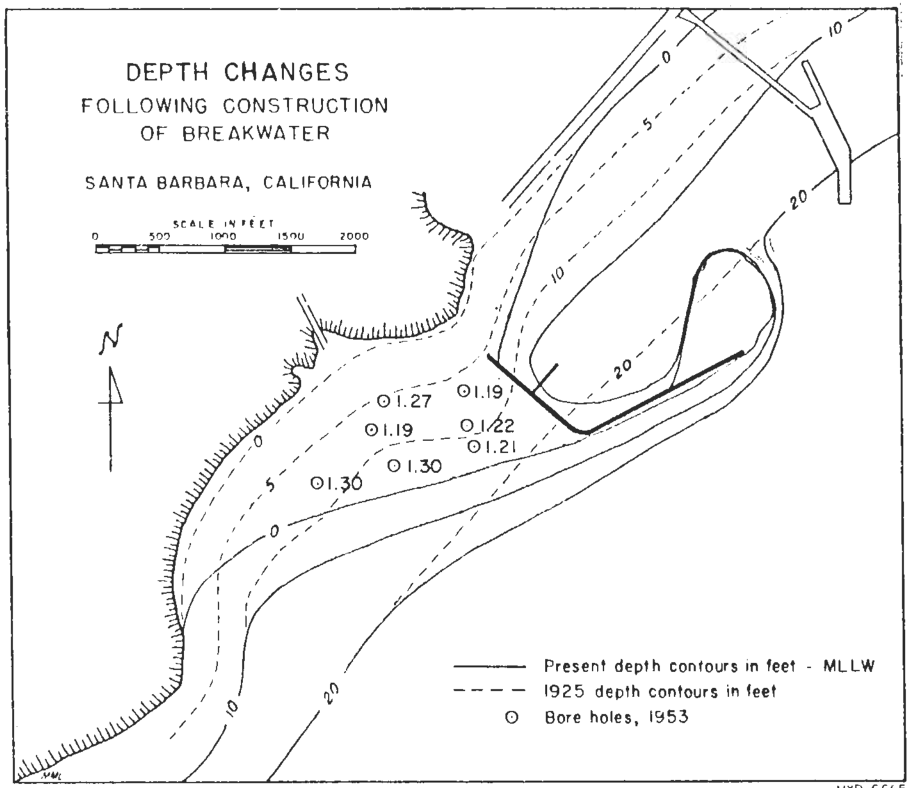
The sorting coefficient for respective depth zones as shown by Fig. 12 indicates no distinctive areal change, although the coefficient is consistently greater in Hole 4 near the seaward edge of the berm than in the other holes, but in Hole 2, likewise near the seaward edge of the berm, the coefficient is essentially the same as in the near shore holes.

The skewness shows no distinctive trend either vertically or areally. The sediments are all rather evenly skewed . The average skewness is close to unity, that is, the logarithm is approximately 0. The general skewness is indicated in Tables VI and VII, and Fig. 14.

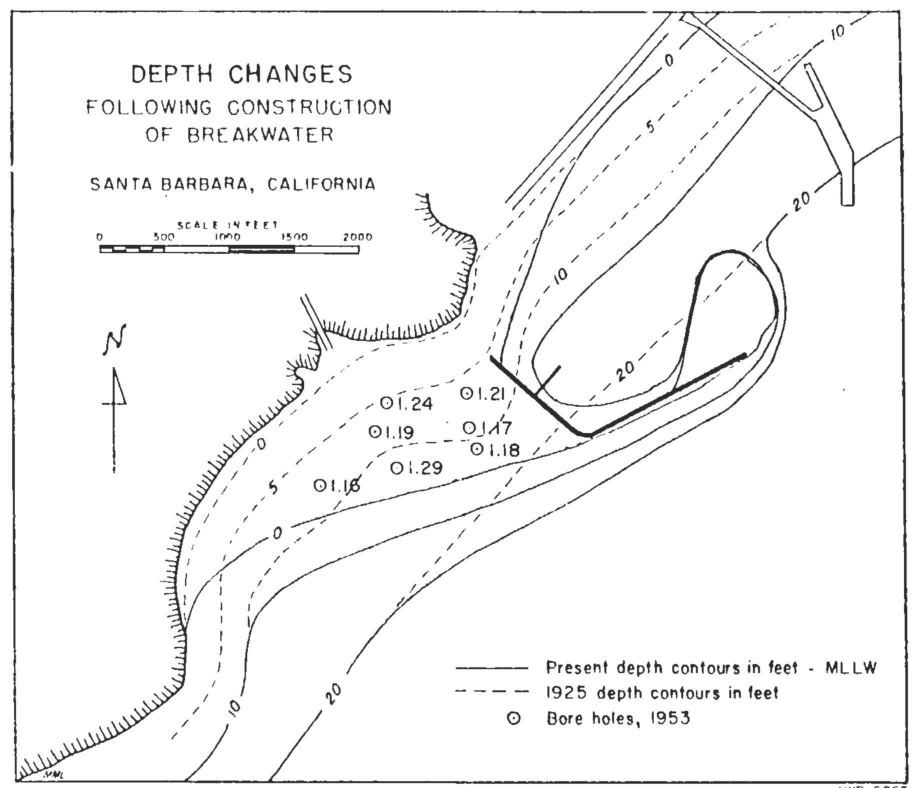
Although the sediments are layered, as is shown by the photographs in Figs. 3 to 5, the mechanical composition varies relatively little from one lamina to another. Tables IV to VI show the extreme variation in individual core samples. The data in these tables represent the maximum parameter observed in any core, divided by the minimum parameter, expressed in terms of percentage of excess. Thus, in Hole 1, depth interval 4 to 7 feet, the maximum diameter is 238 microns and the minimum is 206 microns. The ratio of these two numbers is 238/206, or 1.16; that is, the largest is 16 percent greater than the smallest. The data for skewness (Table VI) are based on the ratios of the actual skewness, not the ratios of the logarithms.

The average excess of maximum median diameter over minimum median diameter for the individual samples in the filled area of the berm is about 14 percent. The extremes for individual samples are 2 percent and 65 percent. The range in median diameter from one core hole to another or from one depth zone to another, as might be expected, is much greater than the range within individual samples. The average (median) range for individual depth zones is 75 percent. The extremes are 19 percent and 128 percent. This indicates that in an individual depth zone throughout the area studied, the average excess of maximum median diameter over minimum is 75 percent. In the depth zones of 13 to 16 feet beneath the top of the berm, where the bottom was 3 to 6 feet deep below MLLW (mean lower low water) as the sand was accumulating, the variation in grain size is 128 percent. That is, the maximum median is 2.28 times the minimum median. On the other hand the variation is only 52 percent or 1.52 times in the depth zone 4 to 7 feet below the top of the berm. In other words, the distribution of effective energy was more variable during the course of deposition of sand in water 3 to 6 feet below MLLW than it was during deposition of sand near the top of the berm. This greater variation in shallow water offshore likewise is characteristic of the old sediments deposited before the breakwater was built. In these sediments the range for individual depth-of-burial zones is relatively large, -- 92 percent in 0 to 3 feet burial, and 157 percent in 3 to 6 feet burial. It should be remembered, however, that these sediments were deposited in 6 to 12 feet of water, compared with a depth of 3 to 6 feet below MLLW for the position of maximum range in the fill samples. Insufficient fill samples were obtained from greater depth of water to give comparable figures for the range. The Pleistocene samples are too few in number to give distinctive figures and the clays were not analyzed. If they had been included in the compilations in Table IV the variation would have been greater than shown.

The coefficient of sorting shown in Table V varies less than median diameter. The average variation within each core sample is 9 percent, and the median variation between depth zones as shown in the column labeled "all cores" is 24 percent. Hole 4 in the most exposed position shows the



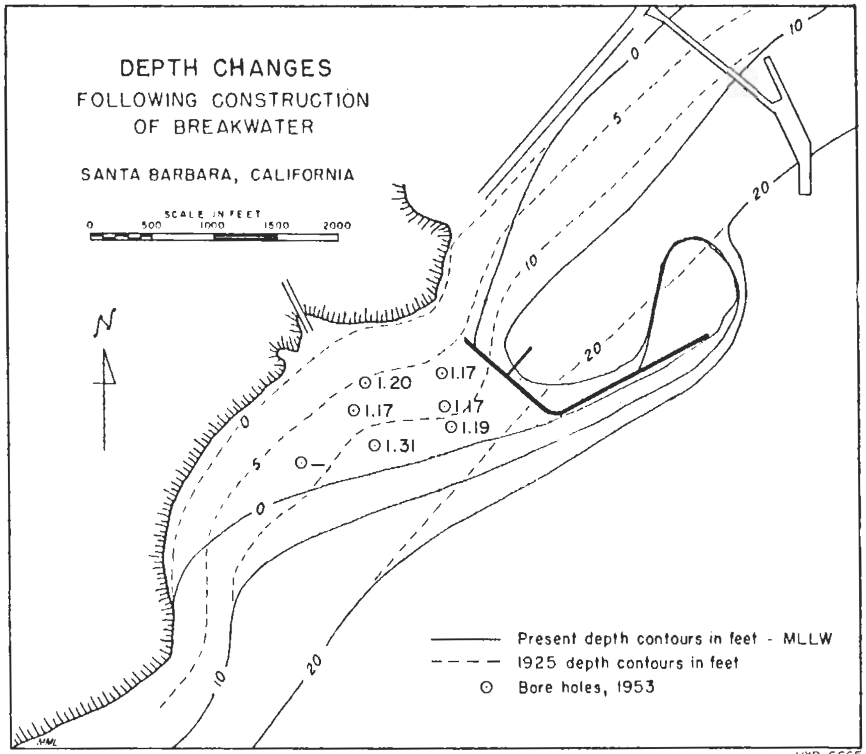
a. 0 to 10 feet below surface of berm.



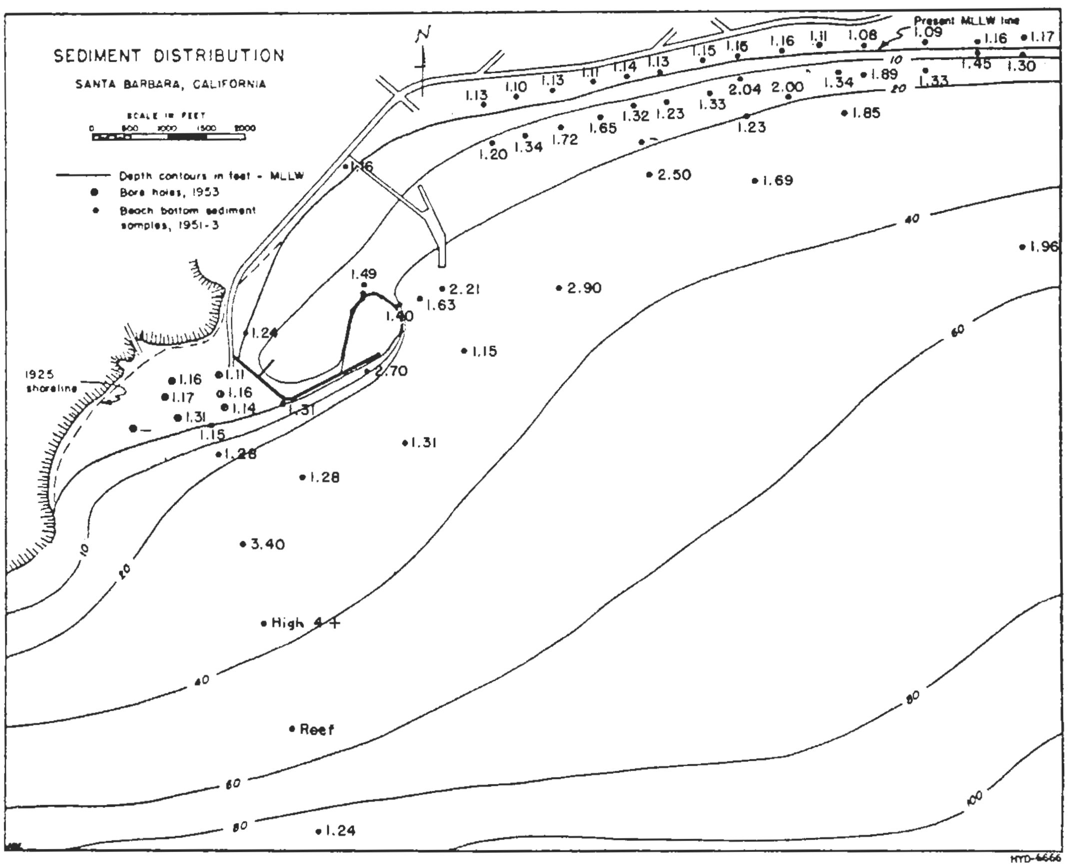
b. 10 to 20 feet below surface of berm

SORTING COEFFICIENT OF CORE SAMPLES

FIGURE 12



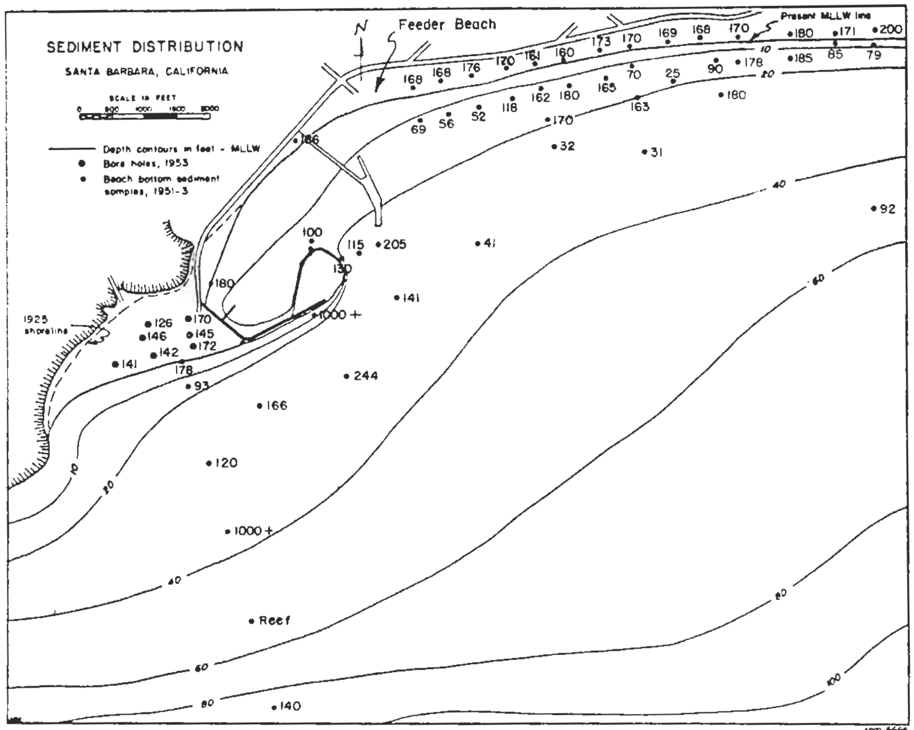
a. O to 6 feet below surface of 1925 sediments



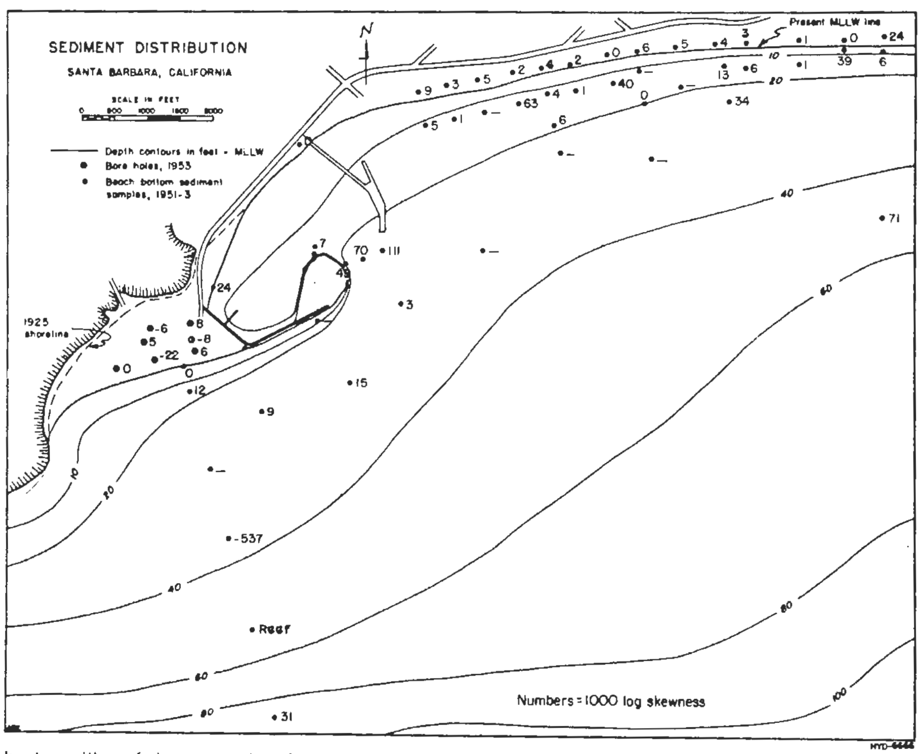
b. Surface sediments; data for bore holes represent surface of sea bottom before construction of breakwater

SORTING COEFFICIENT OF CORE SAMPLES

FIGURE 13



a. Median diameters (microns); data for bore holes represent surface of sea bottom before breakwater construction



b. Logarithm of skewness; data for bore holes represent surface of sea bottom before breakwater construction

DATA ON SURFACE SEDIMENTS

FIGURE 14

greatest variation; the average variation for each core sample in this hole is 16 percent. Hole 6 likewise located upon the edge of the present berm, but 600 feet west of Hole 4 and in a more protected place, varies the least, the average variation within individual cores being only 3 percent. The sediments deposited offshore prior to the construction of the breakwater vary in much the same way as those in the overlying fill. The average variation is 9 percent for individual cores. The Pleistocene samples, as might be expected, varied more.

The skewness, shown in Table VI, varied relatively little within individual cores. The average variation among cores in the fill is 5 percent and in the old sediments beneath the fill, 4 percent. Extremes for individual depth zones are 8 and 39 percent. The greatest variation is shown between depths of 7 to 16 feet beneath the top of the berm, or 0 to 3 feet above MLLW, and for 0 to 6 feet below MLLW. Longshore currents presumably are most effective in this latter depth zone. Variation in skewness perhaps in some way is associated with the effect of such currents. The sediments as a whole are little skewed, as indicated by the data for the average logarithm of skewness in the individual depth zones shown in Table VI. The median logarithm of skewness is 0.003, which corresponds to a skewness of 1.007, remarkably close to unity.

Summary of Results

The results of the mechanical analyses of the core samples are summarized in Table VII. This table presents the average (median), the minimum and maximum median diameter, coefficient of sorting, and logarithm of skewness for each of 3 depth zones for the 3 types of deposits: (1) beach fill, (2) old sediments deposited offshore prior to the construction of the breakwater, and (3) sediments now accumulating on the "Feeder Beach" area east of the breakwater. Figs. 13 and 14 show the median diameter, coefficient of sorting and logarithm of skewness of the samples from the Feeder Beach used for Table VII. These figures also contain data on samples collected west of the Feeder Beach area, which are not used in compiling Table VII, but are shown for general information.

The three depth zones represented in this table are 0 to 10 feet above MLLW, (labeled "A"), 0 to 10 feet below MLLW and 10 to 20 feet below MLLW. In the area of fill west of the breakwater data from zone A represent samples taken between 0 and 10 feet below the top of the berm. In the Feeder Beach area they represent samples collected on the beach face between MLLW and the top of the berm. Most of the samples on this beach were collected at the "reference point" which is 3 to 6 feet above MLLW. No data for zone A are available for the old sediments that accumulated prior to the construction of the breakwater.

The probable error of the averages is indicated in Table VII. For example, the average median diameter of the beach-fill sediments in zone A is given as 206 ± 4 microns. The figure 4 represents the probable error and is the semi-interquartile deviation divided by the square root of the number of samples. As the total number of samples is 50 and the square root of 50 is about 7, the semi-interquartile range of the median diameters in this group of samples is 4 x 7 or 28. That is, the central one-half of the number of samples examined lies within approximately 28 microns of 206, namely between 176 and 234 microns. The adjacent figures of 134 and 278 microns give the total range in diameter. The number 4 for probable error thus is an index of the general spread in data and the relative reliability of the mean. The median diameter as shown in Table VII is lower in depth zone 0 to 10 feet below MLLW than in the zone 10 to 20 feet in depth, in all three types of sediments under consideration. The A zone, that is, that part of the beach above water, contains coarser sediments than in the depth zone 0 to 10 feet below water, as well as in the depth zone 10 to 20 feet below water. The sediments on the beach fill are definitely coarser than comparable sediments in the Feeder Beach area to the east. The average grain diameter in the A zone in the beach fill is 206 microns compared with 170 microns on the Feeder Beach.

The near-shore shallow water zone 0 to 10 feet beneath MLLW has a median of 153 microns in the fill area and 83 microns in the Feeder Beach area. As the Feeder Beach area is represented by only two samples, the figure of 83 microns is not particularly significant. More data are needed for confirmation. The sediments deposited in comparable depth of water in the fill area and the early deposits laid down prior to the construction of the breakwater are roughly comparable, being 153 and 146 microns for the respective deposits in the 0 to 10 foot zone, and 177 and 166 microns in the 10 to 20 foot zone. It should be pointed out that the 10 to 20 foot depth zone in this table is in reality only 10 to 12 feet below MLLW, but the figure of 20 feet is given in order to compare the beach fill area with the Feeder Beach to the east. As the respective differences between the beach fill and the early deposits are small compared with the probable error of the means, the differences cannot be interpreted as being significant. The differences between the fill area and the Feeder Beach, however, are distinctive because the respective differences between the averages are much larger than the probable error of the averages.

The coefficient of sorting is distinctively higher in the A zone of the beach-fill deposits than in the two lower zones, being 1.24 in the former and 1.18 in the latter. No distinctive difference is indicated for the two lower depth zones in the beach fill or the early deposits, where the differences of the means are of the same order as the probable error. The deposits in the A zone of the Feeder Beach are definitely better sorted than those in the A zone of the beach fill, the respective medians being 1.14 and 1.24. The below-water zones in the Feeder Beach area, however, are much more poorly sorted than those in the beach fill or underlying deposits, being 1.34 or more in the former and 1.21 or less in the latter. The poorer sorting in underwater deposits in the Feeder Beach area reflects different conditions of sedimentation. The sediments in that area obviously are not being winnowed as effectively as they are in the beach-fill area.

The progressive decrease in coefficient of sorting with increasing depth in the fill area, noted in Table III and indicated in Table VII by the respective ratios of 1.24 and 1.18 for the A zone and the underlying zones, as mentioned above, is a significant difference. This decrease in sorting coefficient, or better stated, better sorting with respect to depth of burial in the berm, is associated with a corresponding decrease in median diameter, as shown in Tables II and VII. All of the samples come from a relatively short distance of one another and all have been involved in the same process of fill as the berm advanced seaward after the construction of the breakwater. Accordingly, they might be considered as representing one general environment within which sedimentation processes were roughly similar. Thus, the corresponding decrease both in sorting coefficient and grain size perhaps may be the result of a basic relationship between grain size and sorting. This concept has previously been advanced by Inman. (Inman, Douglas, Sorting of sediments in light of fluid mechanics; Jour. Sed. Petrology, vol. 19, pp. 51-70, 1949)

In order to examine this question more fully, median grain diameter was plotted against coefficient of sorting as shown in Fig. 15, The scatter in this figure is large, but the general trend between sorting and median diameter is evident. As data for median diameters smaller than 130 microns or greater than 230 microns are too variable and too scanty to be significant, they are not included in this graph. The relationship is summarized in the following table.

Median diameter Range in microns	Coefficient of sorting Average (median)
130 - 160	1.16
160 - 190	1.20
190 - 220	1.26

This relationship is a regression line characterized by a moderate or low coefficient of reliability. It is not presented here to indicate a general relationship for sediments, but rather with the object of showing that in the size range of particles represented in the fill area at Santa Barbara, the coefficient of sorting to some extent varies with grain size. The coefficient of sorting is influenced by variations in turbulent energy during the time of deposition of the sediments. If, during the process of deposition of sediments turbulent motion deviates considerably from the average, the sediments are likely to be more poorly sorted than if turbulent motion deviates slightly from the average. The fact that the sediments are evenly skewed indicates that deviations of effective energy are evenly distributed on either side of the average. However, the reason for the greater deviations from average turbulence for the coarser sediments than for the finer sediments is not immediately apparent. It may reflect a basic characteristic of motion of water to grain size, as is suggested by the work of Rubey (Rubey, W.W., Settling velocities of sand, gravel and silt particles: Amer. Jour. Sci., vol. 25, pp. 325-338, 1933) and Inman (Op. cit). Rubey's work on the relation of settling velocity to grain size indicated significant changes between grain diameters of 150 and 500 microns. Inman, in his work on the effect of fluid mechanics on sorting, concluded that sediments in process of transport tend to become better sorted as the median diameter approaches 180 microns. The grain sizes of the Santa Barbara samples tabulated above fall within the range of, or are close to, the critical diameters discussed by Rubey and Inman.

If the coefficient of sorting had increased seaward in the same way as did the grain size, it might be argued that the increase was an environmental factor rather than a hydraulic effect, but if so the effect is masked by other factors to such an extent that it is not apparent in the data presented in this paper.

Significance of Results

The object of this paper is to present data upon a series of holes bored through a filled area which covered preexisting shallow water offshore deposits. The investigation is part of a continued series of studies upon

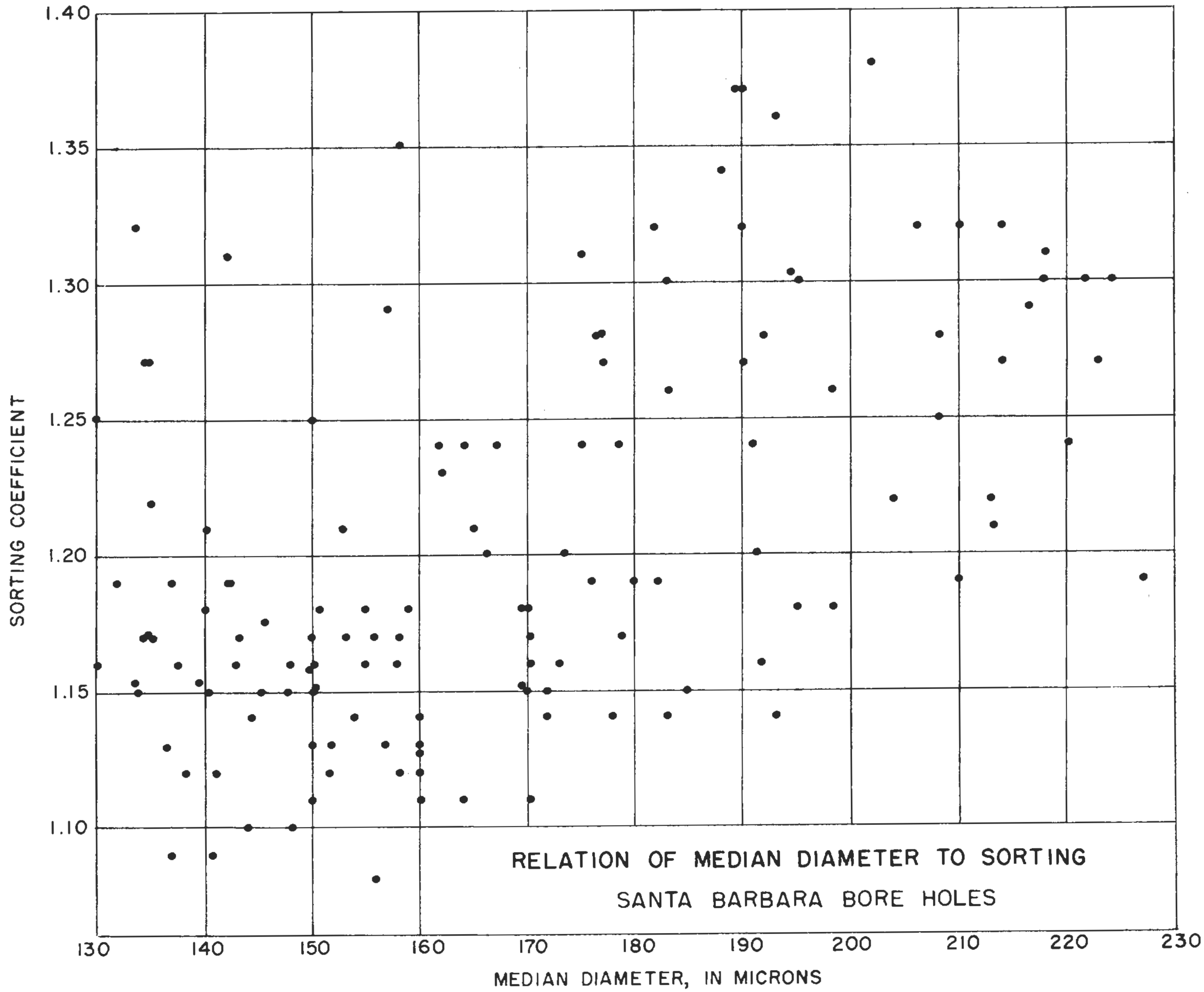


FIGURE 15

HYD-6747

the source of sand and mechanism of sand transport along the Santa Barbara Coast. It would be highly desirable to have more data upon the existing variation in grain size throughout the adjacent offshore area than are now available. The present investigation has shown that the sediments in the filled area west of the breakwater are definitely more coarse grained than in the Feeder Beach area to the east where wave action presumably is gentler. It has also demonstrated that the grain size as well as the coefficient of sorting increase as the berm is built up. The grain size also increases as the berm is built seaward into more exposed positions. Likewise, the sediments immediately offshore in water 0 to 10 feet below MLLW seem to be relatively fine in size compared with sediments on the adjacent beach or in deeper water a short distance seaward. The data are not sufficient to substantiate this last observation, but they do indicate a relationship that is worth investigating further. The interpretation of the significance of these main points can best be postponed to a future paper, or until such a time that more data on the distribution of grain size in the Santa Barbara area have been procured. The important thing is that these four relationships seemingly exist and should be explored further.

Acknowledgments

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TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 1

Core No.	Sample No.	Depth Ft.	Md. Microns	Sorting	Log Skewness
2	1	4.0	210	1.19	0.006
3	1	5.2	206	1.32	-0.004
	2	5.4	210	1.32	0.006
	3	5.6	238	1.27	0.006
4	1	8.4	213	1.22	0.013
	2	8.6	204	1.22	0.002
	3	8.8	190	1.37	0.032
5	2	11.5	165	1.21	0.000
	3	11.7	127	1.26	-0.011
	1(bit)	12.1	155	1.16	-0.013
6	1	14.2	152	1.13	-0.008
	2	14.3	255	1.30	0.011
	3	14.6	160	1.13	-0.004
	4	14.8	140	1.21	-0.013
7	1	17.1	152	1.12	-0.011
	2	17.3	138	1.19	-0.013
	3	17.5	150	1.16	-0.011
	4	17.8	145	1.15	-0.020
		Old sea bottom 19 ft.			
8	1	20.0	157	1.13	0.008
	2	20.3	146	1.17	-0.011
	3	20.5	142	1.19	-0.010
	4	20.7	143	1.16	-0.006
9	1	23.2	150	1.17	-0.010
	2	23.3	158	1.16	-0.008
	3	23.6	160	1.14	-0.007
	4	23.8	196	1.26	-0.008
		Top of Pleistocene 26 ft.			
10	2	26.5	77	1.25	0.010
	3	26.8	79	1.40	0.003
	1(bit)	27.0	89	1.46	0.036
11	Top	27.8	97	1.79	-0.022
	Bottom	28.0	97	1.58	-0.099

Total depth 28 ft.

TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 2

Core No.	Sample No.	Depth Ft.	Md, Microns	Sorting	Log Skewness
12	1	5.3	232	1.23	0.004
	2	5.5	222	1.19	0.000
	3	5.7	208	1.25	0.008
13	1	8.2	208	1.28	0.008
	2	8.5	185	1.15	0.016
	3	8.7	180	1.19	0.030
14	2	11.5	153	1.17	-0.018
	3	11.7	150	1.15	-0.011
	1 (bit)	12.1	157	1.29	0.011
15	2	14.6	175	1.31	0.021
	3	14.8	206	1.46	0.065
	1 (bit)	15.1	125	1.32	-0.034
16	1	17.2	170	1.15	0.008
	2	17.4	170	1.18	0.011
	3	17.5	195	1.18	0.012
	4	17.8	198	1.18	-0.001
17	1	20.0	170	1.17	0.002
	2	20.3	170	1.16	0.002
	3	20.5	192	1.16	0.000
	4	20.7	172	1.15	0.006
		Old sea bottom 22 ft.			
18	1	23.3	183	1.14	0.006
	2	23.5	172	1.14	0.010
	3	23.8	160	1.04	0.004
19	1	26.2	158	1.17	-0.011
	2	26.4	288	1.23	-0.007
	3	26.5	112	1.30	-0.025
	4	26.7	134	1.15	0.002
	bit	27.1	240	1.24	0.003
		Pleistocene at 30 ft.			
20	2	30.6	118	1.98	-0.035
	1 (bit)	31.0	152	1.59	-0.041
21	bit	33.4	115	1.64	-0.033
		Total depth 34 ft.			

TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 3

Core No.	Sample No.	Depth Ft.	Md. Microns	Sorting	Log Skewness
22	2	5.7	223	1.27	0.018
	1 (bit)	6.2	220	1.24	0.018
23	1	8.2	160	1.13	0.014
	2	8.4	160	1.12	0.004
	3	8.5	160	1.11	-0.002
	4	8.7	156	1.08	-0.013
24	1	11.0	190	1.27	0.013
	2	11.2	164	1.11	0.010
	3	11.3	158	1.12	-0.006
	4	11.5	164	1.24	0.015
	5	11.6	155	1.18	0.006
	6	11.8	162	1.23	0.019
25	1	14.2	127	1.22	-0.003
	2	14.4	130	1.16	0.002
	3	14.6	132	1.19	-0.013
	4	14.9	176	1.19	0.011
		Old sea bottom 17 ft.			
26	1	17.2	173	1.16	0.019
	2	17.3	175	1.24	0.031
	3	17.4	170	1.11	0.016
	4	17.6	148	1.10	-0.004
	5	17.9	150	1.11	-0.010
27	2	20.3	153	1.21	0.004
	3	20.6	150	1.25	0.006
	4	20.9	140	1.15	-0.014
	1 (bit)	21.3	135	1.27	-0.036
28	1	23.1	202	1.38	0.025
	2	23.5	150	1.13	-0.019
	3	23.8	125	1.30	-0.029
		Pleistocene at 26 ft.			
29	2	26.4	82	2.34	-0.113
	3	26.7	87	3.22	-0.201
	4	26.8	97	1.53	-0.010
	5	26.9	74	1.57	0.006
	1 (bit)	27.2	98	1.40	-0.006
30	1	29.1	110	1.71	0.022
	2	29.2	98	1.75	0.019
	3	29.3	79	1.58	-0.027
	4	29.5	93	3.51	-0.220
	5	29.7	54	3.02	-0.022
	6	30.0	165	1.27	0.006
	bit	30.2	91	2.17	-0.092

Total depth 30.5 ft.

TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 4

Core No.	Sample No.	Depth Ft.	Md. Microns	Sorting	Log Skewness
31	1	3.3	214	1.32	0.011
	2	3.5	222	1.30	0.025
	3	3.7	193	1.14	0.059
32	1	5.3	224	1.30	-0.001
	2	5.5	268	1.50	-0.013
	3	5.7	249	1.41	0.008
33	1	8.4	195	1.30	0.026
	2	8.6	217	1.29	-0.112
	3	8.7	214	1.27	0.016
34	1	11.4	140	1.18	0.002
	2	11.5	183	1.30	0.035
	3	11.6	225	1.58	0.072
35	1	14.1	182	1.32	0.027
	2	14.3	190	1.32	0.017
	3	14.7	170	1.18	0.008
36	1	17.2	193	1.36	-0.005
	2	17.4	178	1.24	0.019
	3	17.6	182	1.19	-0.012
	4	17.7	170	1.15	0.015
37	1	20.1	188	1.34	0.000
	2	20.3	177	1.27	0.040
	3	20.6	179	1.17	-0.001
		Old sea bottom 22 ft.			
38	2	23.4	177	1.28	0.032
	3	23.6	142	1.31	-0.006
	1 (bit)	23.9	97	1.36	-0.022
		Pleistocene at 28 ft.			
39	2	28.3	142	1.20	-0.005
	3	28.6	160	1.20	-0.012
	1 (bit)	28.9	162	1.23	0.003
		Total depth 29 feet.			

TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 5

Core No.	Sample No.	Depth Ft.	Md. Microns	Sorting	Skewness
Top of Berm	1	0.1	237	1.14	-0.001
	2	0.5	257	1.14	-0.011
	3	0.7	258	1.20	-0.011
40	2	5.8	120	1.65	-0.017
	1(bit)	6.1	158	1.41	0.001
41	3	8.6	166	1.51	-0.018
	4	8.8	190	1.30	0.004
	2(bit)	9.1	167	1.24	0.002
	1(bit)	9.3	162	1.24	-0.011
42	2	11.7	166	1.20	0.022
	1(bit)	12.1	158	1.35	0.011
43	1	15.2	122	1.20	0.013
	2	15.5	136	1.13	-0.002
	3	15.8	112	1.19	-0.006
		Old sea bottom 16 ft.			
44	1	17.2	138	1.12	-0.007
	2	17.4	120	1.15	0.006
	3	17.6	117	1.19	-0.011
	4	17.8	131	1.16	-0.004
45	1	20.3	132	1.22	-0.014
	2	20.5	130	1.32	-0.013
	3	20.9	125	1.24	-0.010
		Top of Pleistocene 24 ft.			
46	2	26.4	94	1.49	-0.018
	1(bit)	26.9	85	1.56	0.000

Total depth 27 ft.

TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 6

Core No.	Sample No.	Depth Ft.	Md. Microns	Sorting	Log Skewness
48	2	5.6	218	1.31	0.004
	3	5.8	232	1.30	-0.017
	1(bit)	6.1	192	1.27	0.003
49	2	8.4	190	1.37	0.034
	3	8.6	150	1.16	-0.011
	4	8.8	135	1.27	0.027
	1(bit)	9.1	134	1.32	-0.035
50	1	11.1	138	1.16	-0.004
	2	11.5	143	1.17	-0.013
	3	11.8	140	1.15	-0.006
51	1	14.1	150	1.16	-0.006
	2	14.3	148	1.16	-0.003
	3	14.6	118	1.19	0.005
	4	14.8	147	1.15	-0.010
52	1	17.1	141	1.12	0.000
	2	17.4	144	1.10	0.000
	3	17.7	134	1.15	-0.002

Old sea bottom 18 ft.

Top of Pleistocene 18 ft.

Total depth 19 ft.

TABLE I

MECHANICAL ANALYSIS OF SANTA BARBARA CORE SAMPLES

HOLE 7

Core No.	Sample No.	Depth Ft.	Md Microns	Sorting	Log Skewness
53	1	5.1	177	1.14	-0.002
	2	5.4	191	1.20	0.003
	3	5.7	213	1.21	0.002
54	1	8.2	278	1.41	-0.008
	2	8.5	156	1.17	-0.012
	3	8.8	151	1.18	-0.006
55	1	11.2	183	1.26	0.030
	2	11.4	191	1.24	0.009
	3	11.5	173	1.20	-0.001
56	1	14.2	141	1.09	0.004
	2	14.4	137	1.09	-0.014
	3	14.7	140	1.15	-0.034
57	1	17.2	117	1.19	0.003
	2	17.4	119	1.18	0.001
	3	17.8	113	1.27	0.003
		Old sea bottom 18 ft.			
58	1	20.2	154	1.14	0.006
	2	20.3	159	1.18	-0.010
	3	20.5	144	1.14	0.005
	4	20.8	146	1.17	-0.001
	5	20.9	127	1.21	0.005
		Top of Pleistocene 24 ft.			
59	2	23.9	81	2.52	-0.229
	3	24.3	102	1.51	-0.053
	1(bit)	24.8	95	1.36	-0.018

Total depth 25 ft.

TABLE II

MEDIAN DIAMETER OF SANTA BARBARA CORE SAMPLES BY DEPTH ZONES.

(Microns)

Depth Interval Ft.	Core Hole 1	2	3	4	5	6	7	Ave.[c] (Median)
				Depth below ground surface[a]				
0-4	210	---	---	222	257	---	---	222
4-7	210	222	222	249	139	218	191	218
7-10	204	185	160	214	164	143	156	180
10-13	155	153	163	183	162	140	183	162
13-16	156	175	131	182	122	147	140	144
16-19	148	183	---	180	---	141	117	151
19-22	---	171	---	177	---	---	---	177
				Depth below 1925 sea bottom[b]				
0-3	145	172	170	142	126	---	146	147
3-6	159	158	145	---	130	---	---	150
6-9	---	---	150	---	---	---	---	150
				Pleistocene sediments				
	79	118	92	160	90	---	95	95

TABLE II-A

DEPTHS AND THICKNESSES
(Feet)

Core Hole 1	2	3	4	5	6	7
Depth of 1925 sea bottom below present surface of berm						
19	22	17	22	16	18	18
Depth to Pleistocene deposits						
26	30	26	28	24	18	23
Thickness of 1925 sediments						
7	8	9	6	8	0	5

(a) Includes only those sediments deposited after breakwater was built.
(b) Includes only those sediments deposited upon Pleistocene bed rock prior to 1925.
(c) All averages are medians and not means.

TABLE III

COEFFICIENT OF SORTING OF SANTA BARBARA CORE SAMPLES BY DEPTH ZONE

Depth Interval Ft.	Core Hole 1	2	3	4	5	6	7	Ave. (c) (Median)
			Depth below ground surface (a)					
0-4	1.19	--	--	1.30	1.14	--	--	1.19
4-7	1.32	1.23	1.26	1.41	1.53	1.30	1.20	1.27
7-10	1.22	1.19	1.12	1.29	1.27	1.30	1.18	1.24
10-13	1.21	1.17	1.21	1.30	1.28	1.16	1.24	1.20
13-16	1.17	1.32	1.19	1.32	1.19	1.16	1.09	1.18
16-19	1.16	1.18	--	1.22	--	--	1.19	1.18
19-22	--	1.16	--	1.27	--	--	--	1.17
			Depth below 1925 sea bottom (b)					
0-3	1.16	1.14	1.11	1.31	1.16	--	1.17	1.16
3-6	1.17	1.23	1.23	--	1.24	--	--	1.23
6-9	--	--	1.30	--	--	--	--	1.30
			Pleistocene sediments					
	1.46	1.18	1.73	1.20	1.52	--	1.51	1.58

TABLE III-A

DEPTHS AND THICKNESSES (Feet)

Core Hole 1	2	3	4	5	6	7
Depth of 1925 sea bottom below present surface of berm						
19	22	17	22	16	18	18
Depth to Pleistocene deposits						
26	30	26	28	24	18	23
Thickness of Sediments						
7	8	9	6	8	0	5

(a) Includes only those sediments deposited after breakwater was built

(b) Includes only those sediments deposited upon Pleistocene bed rock prior to 1925

(c) All averages are medians and not means.

TABLE IV.

VARIATION OF MEDIAN DIAMETER WITHIN INDIVIDUAL DEPTH ZONES

(Data are given in terms of percentage excess of maximum over minimum D_{50} for given depth zones)

Depth Interval Ft.	Core Hole 1	2	3	4	5	6	7	All Cores	No. of Samples
				Beach fill[a]					
0-4		-	-	15	9	-	-	34	7
4-7	16	12	2	20	32	21	19	52	19
7-10	12	15	3	11	17	42	84	107	24
10-13	30	2	16	61	5	4	11	77	23
13-16	82	65	39	12	21	27	3	128	24
16-19	10	16	-	14	-	7	5	75	18
19-22	-	19	-	6	-	-	-	19	7
				Old sediments[b]					
0-3	11	14	18	83	19	-	25	92	24
3-6	24	157	13	-	6	-	-	157	16
6-9	-	-	62	-	-	-	-	62	3
				Pleistocene samples					
	26	29	205	14	11	-	26	205	28

(a) Data refer to depth of samples below surface of berms.

(b) Data refer to depth of samples below the 1925 sea bottom.

TABLE V

VARIATION OF COEFFICIENT OF SORTING OF SANTA BARBARA CORE SAMPLES BY DEPTH ZONES

(Data are given in terms of percentage excess of maximum over minimum coefficient of sorting for given depth zones)

Depth Interval Ft.	Core Hole							All Cores	No. of Samples
	1	2	3	4	5	6	7		
				Beach fill[a]					
0-4		--	--	16	5	--	--	16	7
4-7	4	5	3	15	16	3	6	45	19
7-10	13	11	5	16	22	18	21	40	24
10-13	9	13	15	34	13	2	5	42	23
13-16	15	11	5	12	6	3	5	34	24
16-19	6	2	--	18	--	4	7	24	18
19-22	--	2	--	15	--	--	--	16	7
				Old sediments[b]					
0-3	5	9	13	6	6	--	6	32	24
3-6	10	12	10	--	8	--	--	15	16
6-9	--	--	22	--	--	--	--	22	3
				Pleistocene samples					
	43	25	100	2	5	--	85	192	28

(a) Data refer to depth of samples below surface of berms
(b) Data refer to depth of samples below the 1925 sea bottom.

TABLE VI

VARIATION OF LOGARITHM OF SKEWNESS WITHIN INDIVIDUAL DEPTH ZONES

(Data are given in terms of percentage excess of maximum over minimum skewness for given depth zones)

Depth Interval Ft.	Core Hole 1	2	3	4	5	6	7	All Cores	Ave. Log Skewness	No. of Samples
				Beach fill[a]						
0-4		--	--	12	2	--	--	15	.006	7
4-7	2	2	0	5	4	5	1	8	.003	19
7-10	7	5	6	34	5	11	1	39	.004	24
10-13	3	7	6	17	3	1	7	23	.006	23
13-16	6	26	5	4	4	3	9	26	-.002	24
16-19	2	3	--	7	--	0	0	9	.000	18
19-22	--	1	--	9	--	--	--	9	.002	7
				Old sediments[b]						
0-3	6	1	10	13	4	--	3	13	.002	24
3-6	1	4	10	--	1	--	--	10	-.010	16
6-9	--	--	11	--	--	--	--	11	-.019	3
				Pleistocene samples						
	29	2	75	3	4	--	63	75	-.020	28

(a) Data refer to depth of samples below surface of berms.
(b) Data refer to depth of samples below the 1925 sea bottom.

Note that data are computed upon basis of skewness rather than logarithm of skewness.

TABLE VII

SUMMARY OF SEDIMENT PARAMETERS, SANTA BARBARA, CALIFORNIA.

Depth[a] Interval Ft.	No. of Samples	Median Diameter (Microns)			Coefficient of Sorting			Logarithm of Skewness		
		Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
					Beach fill[b]					
A	50	206±4	134	278	1.24±.01	1.08	1.65	.003±.001	-.112	.059
0-10	65	153±4	113	255	1.18±.01	1.09	1.46	.000±.001	-.034	.072
10-20	7	177±3	170	192	1.17±.02	1.15	1.34	.002±.001	-.001	.040
					Early deposits[c]					
0-10	18	146±3	117	175	1.16±.01	1.10	1.24	-.003±.002	-.011	.031
10-20	6	166±10	97	183	1.21±.04	1.04	1.36	.001±.003	-.022	.032
					Feeder Beach deposits[d]					
A	16	170±2	160	200	1.14±.01	1.08	1.24	.004±.001	.000	-.024
0-10	2	83±1	79	85	1.38±.03	1.30	1.45	.023±.007	.006	.039
10-20	13	118±14	25	185	1.34±.06	1.20	2.04	.006±.005	.001	.063
					Pleistocene deposits[e]					
	27	95±2	54	165	1.58±.05	1.20	3.51	-.020±.004	-.229	.022

(a) Depth interval represents depth below mean lower low water - letter **A** refers to beach sediments 0-10 feet above mean lower low water level. Top of berm is at 10 feet.

(b) Sediments in filled area where core holes were drilled.

(c) Sediments within three feet of surface of sea bottom prior to construction of breakwater. Depth refers to depth of water at that time.

(d) Deposits now accumulating east of breakwater. Depth refers to present depth.

(e) Pleistocene sand samples beneath sediments in the filled area West of the breakwater.